CHAPTER 7

STANDARDS FOR AUTOMATED LOCAL FLOOD WARNING SYSTEMS

7.1 Overview

The primary purpose of LFWS standards is to ensure compatibility with NWS systems and operations. Any system meeting the standards specified in this chapter could effectively send data to NWS offices and receive products from NWS offices. In addition, these standards describe the sensor transmission system, the sensor communication protocols, and the data and product exchange formats of the "baseline" automated LFWS. The assumption is that private vendors are likely to market systems providing enhancements beyond this functional baseline, but NWS will not provide software with capabilities beyond the baseline. However, it is the intent of the NWS to structure the baseline software to facilitate the addition of applications to it by individual users. The NWS is free to enhance systems installed in its own offices as resources permit.

Although NWS standards for an automated LFWS establish technical requirements for compatibility with the NWS, they do not supersede regular policy channels for establishing NWS links to an automated LFWS under a properly ratified MOU. Meeting these standards is a necessary but not sufficient condition for exchange of information with the NWS.

7.1.1 Network-Configured System

Through congressional mandate, NWS developed and supported implementation of IFLOWS. The NWS initially developed cooperative agreements with selected Appalachian state emergency services agencies. Under these agreements, NWS (1) develops the system design, (2) provides equipment and software, (3) provides upgrades to software, (4) supports equipment replacement, and (5) provides continuing technical support. Since its initial implementation, IFLOWS technology has expanded into other areas. Each participating state operates and maintains the system within its boundaries. As a result of its continuing involvement in IFLOWS, NWS exercises a significant degree of configuration management authority, both hardware and software and both government and vendor supplied. This is critical to the ability of the NWS to effectively manage IFLOWS.

IFLOWS usually operates as a wide-area network with two-way communication capability (voice, data, and text). These NWS-developed systems include specific software loads that operate in a limited number of hardware environments. The IFLOWS software is available to others outside the IFLOWS program area.

7.1.2 Stand-Alone-Configured System Standards

Configurations of stand-alone, computer-based LFWSs, in particular ALERT systems, are funded, operated, and maintained by many cooperators. The original ALERT was developed in the NWS Western Region; Western Region has set standards for support of this suite of software. There are private vendor ALERT systems as well. The NWS may provide

NWS-developed software for a specific hardware configuration, or the cooperator may contract with private sources for this software. These LFWSs operate basically in a stand-alone configuration with one-way data collection per community or group of communities.

7.2 ALERT/IFLOWS Gage Formats

Message format for ALERT/IFLOWS observation platforms, as adopted by the AUG, is:

1. ALERT/IFLOWS data transmissions utilize a frequency shift which represents a "zero" with a 1920 Hz audio tone and a "one" with a 2133 Hz audio tone. These frequencies are not compatible with Bell 202 in isolating ALERT messages from the many interference sources that commonly utilize Bell-compatible message forms. This technique has not resulted in any discernible increase in manufacturing costs and helps to reduce the potential for decodable interference while maintaining a minimum message length.
2. ALERT/IFLOWS may use 300 or 1200 baud; however, 300 baud is recommended. Although 1200 baud has apparent advantages for automated data collection sites, these advantages may be illusory. The 1200-baud messages require better radio paths than are needed for 300-baud data recovery. Many remote sites now operating at 300 baud are at the margins of adequate data recovery and are not capable of operating at 1200 baud. The future requirement for "narrow banding" will alter radio transmission characteristics in a manner that will make the difficulties of using 1200 baud even more severe. These factors weigh against the use of 1200 baud in any area where data are needed from sites with marginal radio paths.
3. Each ALERT/IFLOWS message consists of 40 bits, representing four 8-bit characters, each preceded by a single start bit and followed by a single stop bit. The following table shows the order of transmission reading from **right to left**, then from **top to bottom.**

< -- Transmission Order < --

Stop	0	1	A_5	A_4	A_3	A_2	A_1	A_0	Start
Stop	0	1	A_{11}	A_{10}	A_9	A_8	A_7	A_6	Start
Stop	1	1	D_4	D_3	D_2	D_1	D_0	A_{12}	Start
Stop	1	1	D_{10}	D_9	D_8	D_7	D_6	D_5	Start

where:

A_i is the i^{th} bit of the reporting sensor address, where A_0 is the least significant bit and A_{12} the most significant.

D_i is the i^{th} bit of the reporting sensor data (accumulator) value, where D_0 is the least significant bit and D_{10} the most significant.

Start is the start bit for each character. It is always a space (0).

Stop is the stop bit for each character. It is always a mark (1).

This format provides an identifier range of 0 through 8191 and a data range of 0 through 2047. The bits identified with 1 or 0 are used to confirm that an incoming message is formatted in the ALERT/IFLOWS binary code.

4. No check sums or multiple transmissions are utilized in order to minimize interstation interference.
5. All sites shall transmit their principal sensor identifier and its current accumulator value at 12-hour intervals.

7.2.1 Enhanced IFLOWS Format for IFLOWS Gages

The Enhanced IFLOWS Format (EIF) is an alternative message format for IFLOWS observation platforms. EIF is fully compatible with ASCII and binary formats and can coexist on a single radio frequency with platforms that use these formats. Moreover, since EIF changes only the ***content*** of the message, implementation in microprocessor-controlled platforms should involve simple reprogramming. All other characteristics of reports, including message length, bit polarity, and frequency shift keying (FSK) tones used to encode mark and space states, remain unchanged.

Each IFLOWS message consists of 40 bits, representing four 8-bit characters, each preceded by a single start bit and followed by a single stop bit. The following table shows the order of transmission reading from ***right to left***, then from ***top to bottom***.

< -- Transmission Order < --

Stop	1	1	A_5	A_4	A_3	A_2	A_1	A_0	Start
Stop	D_0	A_{12}	A_{11}	A_{10}	A_9	A_8	A_7	A_6	Start
Stop	D_8	D_7	D_6	D_5	D_4	D_3	D_2	D_1	Start
Stop	R_0	R_1	R_2	R_3	R_4	R_5	D_{10}	D_9	Start

where:

A_i is the i^{th} bit of the reporting sensor address, where A_0 is the least significant bit and A_{12} the most significant.

D_i is the i^{th} bit of the reporting sensor data (accumulator) value, where D_0 is the least significant bit and D_{10} the most significant.

R_i is the coefficient of the i^{th}-order term in the remainder polynomial (see below).

Start is the start bit for each character. It is always a space (0).

Stop is the stop bit for each character. It is always a mark (1).

Calculating The Remainder Polynomial

Ignoring start and stop bits (which serve only to frame characters and are discarded by receiver hardware), a gage report consists of 32 data bits transmitted serially. The first bit transmitted is A_0 and the last is R_0. Each bit may be considered the coefficient of a term in a 31^{st} order polynomial of some arbitrary variable x; A_0 is the coefficient of x^{31}, A_1 of x^{30}, and so forth, with R_0 the coefficient of x^0.

To create a message, store the sensor address and data in the A_i and D_i fields, respectively, and zero all R_i bits. Using modulo-2 arithmetic, divide the message polynomial by the EIF generator polynomial $x^6 + x^4 + x^3 + 1$ and add the remainder (a polynomial of order 5 or less) to the original message (the addition has the effect of setting R_i to the coefficient of x^i in the remainder polynomial). The resultant message is transmitted as outlined above.

When a receiver detects a message whose first byte has the form 11*xxxxxx*, it assumes the format is EIF. Treating the message as coefficients of a 31^{st} order polynomial of x and using modulo-2 arithmetic, the receiver divides it by the generator polynomial. If the remainder is not zero, the message suffered one or more errors during transmission and should be discarded. Otherwise, the message is presumed correct (although it may contain an undetected error) and is processed accordingly.

Undetected errors occur when the transmitted and received message polynomials differ by a polynomial (called the error polynomial) of which the generator polynomial is a factor. If all possible error polynomials were equally likely, the EIF would fail to detect one error in 64. However, some errors, such as one-bit and two-bit errors, are far more common than others. By choosing a generator polynomial carefully, one can improve the probability of detecting all (or most) common errors dramatically. The selected EIF generator $x^6 + x^4 + x^3 + 1$ detects all one-bit and two-bit errors, all errors affecting an odd number of bits, all burst errors of length 6 or less, 96.9 percent of seven-bit burst errors, and 98.4 percent of all other errors.

7.2.2 The ALERT Users Group Enhanced Format

The binary format that both the ALERT and IFLOWS systems used has an excellent range for sensor identification and data description. In addition, the message format is very well defined by start, stop, and format identifier bits; however, the binary format has no internal data-checking capability. In 1988, the Technical Review Committee of the AUG conducted a survey of over 40,000 ALERT messages. In this sampling, about 300 messages (approximately 0.7 percent of the decoded messages) had errors that might have been avoided by using a format with internal message-checking capability. The Committee, composed of ALERT users, equipment providers, hydrologists, meteorologists, equipment maintenance personnel, and software writers, suggested the application of an error-checking or enhanced format in an attempt to reduce the apparent error rate that had been associated with the binary format. In May of 1988, at the annual meeting of the AUG, an enhanced format recommended by the Technical Committee was approved as an alternate format for conjunctive use in the ALERT system. The enhanced format incorporated a cyclic redundancy check (CRC) for message checking and a battery-level indicator to guide field maintenance personnel. However, in order to avoid a decline in the system's throughput capability, the message was not altered. The bit structure of the enhanced format was organized so that it could operate concurrently with the earlier formats. Thus, if the new format proved successful, equipment that utilized earlier formats could be modified or replaced through attrition rather than requiring a simultaneous replacement of field equipment. The format selected as the AUG enhanced format is the following:

Character One

Bit Number	Significance			
1	Start Bit			
2	Sensor Identifier	0	or	1
3	Sensor Identifier	0	or	2
4	Sensor Identifier	0	or	4
5	Sensor Identifier	0	or	8
6	Sensor Identifier	0	or	16
7	Sensor Identifier	0	or	32
8	1 Format Identifier			
9	1 Format Identifier			
10	1 Stop Bit			

Character Two

Bit Number	. . . . .	Significance			
1	. . . . . .	Start Bit			
2	. . . . . .	Sensor Identifier	0	or	64
3	. . . . . .	Sensor Identifier	0	or	128
4	. . . . . .	Sensor Identifier	0	or	256
5	. . . . . .	Sensor Identifier	0	or	512
6	. . . . . .	Sensor Identifier	0	or	1024
7	. . . . . .	Sensor Identifier	0	or	2048
8	. . . . . .	Data Value	0	or	1
9	. . . . . .	Data Value	0	or	2
10	. . . . . .	Stop Bit			

Character Three

Bit Number	. . . . .	Significance			
1	. . . . . .	Start Bit			
2	. . . . . .	Data Value	0	or	4
3	. . . . . .	Data Value	0	or	8
4	. . . . . .	Data Value	0	or	16
5	. . . . . .	Data Value	0	or	32
6	. . . . . .	Data Value	0	or	64
7	. . . . . .	Data Value	0	or	128
8	. . . . . .	Data Value	0	or	256
9	. . . . . .	Data Value	0	or	512
10	. . . . . .	Stop Bit			

Character Four

Bit Number	. . . . .	Significance			
1	. . . . . .	Start Bit			
2	. . . . . .	Data Value	0	or	1024
3	. . . . . .	Battery Level Bit			
4	. . . . . .	CRC Bit			
5	. . . . . .	CRC Bit			
6	. . . . . .	CRC Bit			
7	. . . . . .	CRC Bit			
8	. . . . . .	CRC Bit			
9	. . . . . .	CRC Bit			
10	. . . . . .	Stop Bit			

Integrating a six-bit CRC within the enhanced format was intended to ensure that the station identifier and data value were received with virtually no possibility of error. Due to the complexity of the process, the technique for computing the CRC will not be included in this description. Using a battery-level indicator was intended to provide a method for identifying when the battery voltage at the sensor site had dropped to a level that was likely to require immediate field maintenance. These additions were accomplished by reducing the number of sensor identifiers to 4095 and the bits available for format identification from eight to two.

7.3 ALERT/IFLOWS Functional Capabilities

The radio-reporting rain gage (RRRG), the most common sensor platform found in the LFWS, is a device used to measure and report rainfall from remote locations. It is installed outdoors, unattended, and often in remote or unprotected areas where commercial power is generally unavailable. The RRRG is a hollow metal tube, 12 feet in height and 1 foot in diameter. Mounted inside the top of the tube is a screened funnel and an electromechanical tipping bucket. Side-mounted near the top of the tube is a radio-transmitting antenna. Inside the tube's underground footing is the RRRG electronics package: a battery-powered, microprocessor-controlled counter and a radio transmitter.

When 1 millimeter of rain fills the RRRG's hinged bucket through the top opening of the funnel, the bucket resets itself, spilling the water and tripping a switch. The switch causes the electronics package to generate a sensor address which ranges from 00 to 8191. A radio transmitter in the electronics package sends a four-byte message by audio tones. At 300 baud, the resulting radio report requires 133 milliseconds to convey its data message. The transmitter is turned on and brought up to its operating power level prior to transmitting the data report. If no relays are utilized in this system, about 70 milliseconds are required prior to transmitting the data message. The warm-up time must be extended by approxi-mately 50 milliseconds for each relay that is necessary to pass the message. Each remote data site reports its operational status by transmitting its principal sensor address and its current accumulator value twice per day.

In addition to reporting rainfall in ALERT/IFLOWS message format, various other environmental sensors (such as river stage, wind speed and direction, barometric pressure, temperature, relative humidity, water quality, and soil moisture) are marketed with this reporting format.

7.4 Selected ALERT/IFLOWS Technical Specifications

The sensor transmitter provides the capability of recognizing and encoding data from the sensors and then transmitting the resulting information in real time on appropriate radio frequencies. The transmitter must be self-powered and shaped to fit into the base of the rain gage support tube. The transmitter package must operate at unpowered, remote sites with a high level of reliability and the lowest possible maintenance requirements. In order to encourage the broadest possible involvement of many diverse organizations, the basic transmitter package must be as simple, reliable, and low priced as possible. At the same time, it must have the potential for cost-effective modifications that support the operation of a broad range of ancillary hydrometeorological sensors. In order to accomplish these objectives, the following specifications are necessary:

1. The sensor transmitter shall have a convenient means of setting a station ID that corresponds to the range of values appropriate to the transmission code in use. The number selected shall represent the input port used for the incremental precipitation sensor. Other incremental (digital) sensors shall utilize IDs that decrease from the precipitation sensor's ID. Analog sensors shall be identified in sequence by adding "1" to the previous sensor ID. If a precipitation gage is not attached to the transmitter, the station ID shall represent water level.
2. The sensor transmitter shall provide a means of varying the warm-up time prior to transmitting the data signal. Signal modulation would be capable of successful decoding at a base station with a lead-time of 100 milliseconds and through a relay system with proportionally longer lead-times. However, the warm-up time shall not exceed 600 milliseconds.
3. The sensor transmitter shall transmit check signals at approximately 12-hour intervals utilizing a single sensor as the principal station ID. This ID will be rainfall if the station is equipped with a rain gage.
4. The sensor transmitter shall use an FSK transmission form and be FCC type accepted (type certified to Part 90 and Part 2). VHF transmitters shall utilize a variable output power not to exceed 25 watts. Output levels shall be kept low to conserve battery life yet high enough to assure dependable transmission of data.
5. Transmissions shall be frequency controlled and consistent with FCC regulations through an operating range of -20 °C to +60 °C.
6. Transmitted messages shall conform to Logic 1 at 2133 Hz and Logic 0 at 1920 Hz.
7. The transmitter shall operate on those frequencies licensed for the transmission of hydrometeorological data.
8. To restrict extraneous transmissions of water levels in event-driven, digital, bidirectional water level sensors, the device shall be designed with the following features:

    a. A user-selectable lockout time to prevent consecutive transmissions occurring within a predefined time interval.

       Example: A rotary switch with positions 0 through 9 might use 9 to create a 1-hour (3600-second) lockout. Each decreasing switch position would cut the lockout time in half. Lockouts for switch positions 9 through 0 would create lockouts of 3600, 1800, 900, 450, 225, 112, 56, 28, 14, and 7 seconds, respectively.

b. The capability of varying the number of increments beyond a single increment that must occur to constitute an event and generate a transmission.

Example: 0 through 9 additional increments

c. An override that initiates a transmission during the lockout time if an indicated number of events should occur.

Example: If "5" is selected on an override switch, then five events occurring in the lockout time would override the timed lockout, and the fifth event would be transmitted.

9. The electronic package shall allow up to four digital (incremental) and eight analog sensors to operate with a common transmitter.
10. All analog sensors shall be read and transmitted on a user-determined time schedule controlled by an internal clock in the electronic package.

    Example: The available choices might include: Event, 3, 7, 10, 15, 20, and 30 minutes, 1, 2, 3, 4, 5, 6, and 12 hours.

11. The ID assignments for transmitters configured for weather station use shall conform to the following schedule:

ID-3	Wind run and direction
ID-2	Optional event sensor
ID-1	Event river sensor
ID	1 millimeter event precipitation gage
ID + 1	Relative humidity
ID + 2	Temperature
ID + 3	Optional analog sensor
ID + 4	Atmospheric pressure

Additional ports shall be used for appropriate hydrometeorological sensors.

12. The transmitter features defined for water-level transmissions in item 8 shall also apply to wind run. However, the timed lockout shall have an override with no more than eight units of wind run.